CLAIMS

What is claimed is:

1. A method for operating a fuel cell system in sub-freezing ambient temperatures, wherein the system includes a stack of PEM fuel cells including at least one cooler for carrying antifreeze through the stack to remove heat from the stack, each cell including a water transport plate and having water flow passages therethrough, the method including the steps of: a) draining any liquid water from the cell water flow passages upon or after the previous shut-down of the stack before freezing can occur, and thereafter b) starting-up the stack by directing fuel and oxidant reactants into the cell and connecting a load to the stack; c) using heat produced by the stack to increase the operating temperature of the stack to at least 0°C to melt any ice within the cells; and, d) upon the stack operating temperature reaching at least 0°C, circulating anti-freeze through the stack coolers to maintain the operating temperature of the stack low enough to prevent cell dry out for at least as long as liquid water does not circulate through the water flow passages.

2. The method according to claim 1, wherein the fuel cell system includes a water circulation system for circulating water through the water flow passages of the cells, the water circulation system including a water accumulator; wherein the step of draining liquid water from the water flow passages includes draining substantially all liquid water from the water circulation system.

3. The method according to claim 1, wherein the antifreeze circulation is not started until the operating temperature of the stack is at least 10°C.

4. The method according to claim 1, wherein the antifreeze circulation is not started until the operating temperature of the stack is at least 30°C.

5. The method according to claim 4 wherein during stack operation without water circulating within the water flow passages of the cells, the operating temperature of the stack is maintained at no more than about 40°C.

6. The method according to claim 2 including, during operation after start-up, the step of collecting cell product water within the accumulator and, after a sufficient amount of water has been collected within the accumulator to enable circulation of water through the water flow passages, circulating the water through the water flow passages and allowing the stack operating temperature to increase to normal operating levels.

7. The method according to claim 1, wherein the fuel cell system includes a water circulation system for circulating water through the water flow passages of the cells, the water circulation system including a water accumulator, wherein upon start-up of the stack the water circulation system has water within the accumulator, wherein the step of starting up the stack includes melting any frozen water within the accumulator and, when sufficient liquid water is available within the water circulation system, circulating liquid water through the cell water flow passages.

8. A method for operating a fuel cell system when ambient temperatures may be below the freezing point of water, wherein the fuel cell system includes a stack of fuel cells, each cell including a proton exchange membrane sandwiched between an anode water transport plate on the anode side of the membrane a cathode water transport plate on the cathode side of

the proton exchange membrane, an anode catalyst layer adjacent the anode side of the proton exchange membrane, a cathode catalyst layer adjacent the cathode side of the proton exchange membrane, and a cooler separating at least one pair of adjacent cells in the stack for carrying anti-freeze through the stack, the cooler being connected to an anti-freeze circulating system, each cell also including water flow passages therewithin connected to a water circulating system, said method comprising the steps of (a) starting the fuel cell system without water within said water flow passages, including flowing air over the cathode side of the proton exchange membrane, flowing fuel reactant gas over the anode side of the proton exchange membrane, and connecting the load to the stack, (b) operating the stack without circulating antifreeze coolant through the coolers at least until the heat generated by the stack raises the stack temperature above 0°C, and, thereafter, (c) circulating anti-freeze through the coolers to maintain the stack at below normal operating temperatures for the period of time that no liquid water circulates through the water circulation system, said below normal stack temperatures being low enough to prevent cell dry out during said period of time, and (d) upon shut down of the system, drain all liquid water from the water flow passages before it freezes.

9. The method of claim 8, wherein said antifreeze circulation is not started until frozen water, if any, within the stack has started to melt.

10. The method of claim 8, wherein said antifreeze circulation is not started until all frozen water, if any, within the stack has melted.

11. The method according to claim 1, wherein sub-freezing temperatures are expected during a selected

period of the year, and wherein the fuel cell system includes a water circulation system for circulating water through the water flow passages of the cells, the water circulation system including a water accumulator, and wherein prior to said step (a), (i) draining all liquid water from the accumulator and keeping it empty for said selected period of the year; and (ii) preventing water from circulating through the water flow passages and water circulation system for said selected period of the year, wherein steps (a) through (d) are done throughout said selected period of the year without water circulating through the water flow passages.

12. The method according to claim 9, wherein the below normal temperatures of step (c) are no greater than 40°C

13. The method according to claim 11, wherein antifreeze circulation is not started until the operating temperature of the stack is at least 10°C.

14. The method according to claim 11, wherein during stack operation without water circulating within the water flow passages of the cells, the operating temperature of the stack is maintained at no more than about 40°C.

15. The method according to claim 2, wherein product water from operation of the stack is accumulated within the accumulator until sufficient liquid water has accumulated in the water circulation system to enable circulation of that water through the water flow passages; and, thereafter, initiating and continuing circulation of the accumulated water through the water flow passages and circulation system and allowing the temperature of the stack to rise to normal operating temperatures.

16. The method according to claim 8, wherein circulation of the anti-freeze is initiated only after the stack temperature has increased to at least 10°C.

17. The method according to claim 8, wherein at some time before shut-down the water circulation system begins to circulate water through the water flow passages, at which time the temperature of the stack is allowed to rise to normal operating temperature.

18. A method of shutting down and restarting a fuel cell system comprising a stack of proton exchange membrane fuel cells wherein the stack, at or after a system shut-down and prior to the next system start-up, is exposed to below freezing temperatures, and wherein each of said cells includes a fuel reactant gas flow field on an anode side of the cell, an oxidant reactant gas flow field on a cathode side of the cell, a cooler separating at least one pair of adjacent cells in the stack to remove heat from the stack, the stack also including water flow passages therewithin connected to a water circulating system for circulating water through the water flow passages, including the steps of (a) shutting down the fuel cell system while it is generating electrical power by disconnecting the stack from its load, halting the flow of reactants, halting any circulation of water through the water passages, and draining the liquid water from the water passages; and, thereafter, (b) initiating start-up of the system by (i) flowing air to the oxidant reactant gas flow fields and fuel reactant gas to the fuel reactant gas flow fields, (ii) connecting the load to the stack, and (iii) operating the stack at part power at least until the stack temperature is above 0°C and any frozen water

within the stack is melted; and, thereafter (c) initiating and maintaining the circulation of anti-freeze through the cooler to maintain the stack temperature at below normal stack operating temperatures at least until the water circulation system is able to circulate water through the water passages, wherein such below normal temperatures are low enough to prevent cell dry out; and, thereafter, (d) initiating and continuing circulation of water through the water passages and circulation system and allowing the temperature of the stack to rise to normal operating temperatures until the system is shut down.

19. The method of claim 18, wherein the step of initiating circulation of anti-freeze is done after the stack temperature has increased to at least 10°C, and the below normal temperatures of step (c) are no greater than about 40°C.

20. The method of claim 18, wherein the step (a) of shutting down the stack includes draining the liquid water from the entire water circulation system.

21. The method of claim 6, wherein the water circulation system includes a water accumulator for holding water used for water circulation through the water flow passages of the cells, and wherein upon and during shut-down of the stack the water accumulator is not drained, and step (b) includes melting frozen water in the accumulator, if any, after initiating start-up, by using energy generated by the stack.